User Guide for the Orbit Viewer THOR

Version 2.2

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Developed by the Precipitation Processing System (PPS)
https://pps.gsfc.nasa.gov

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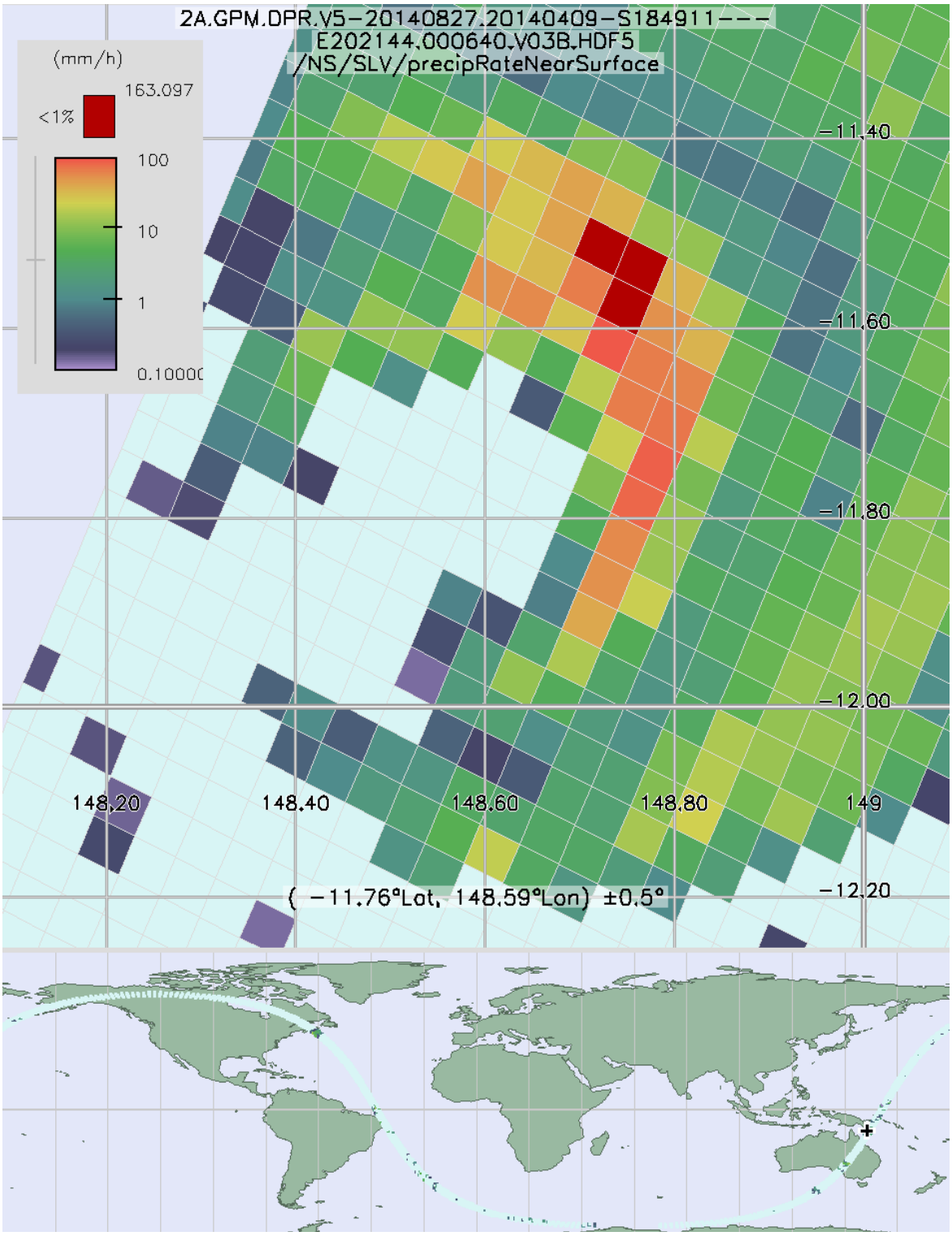

Cyclone Ita. The Global Precipitation Measurement (GPM) Dual-frequency Precipitation Radar (DPR) observed Cyclone Ita on April 9, 2014. The data in the image are near surface precipitation-rate estimates from the 2ADPR data product. The Orbit Viewer THOR created this image.

PUBLICATION HISTORY

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To obtain a copy of the Orbit Viewer or this user guide, visit the PPS Web site [https://pps.gsfc.nasa.gov].

The Orbit Viewer for GPM and TRMM data was developed by the National Aeronautics and Space Administration (NASA), and any use of it should be acknowledged. The GPM and TRMM data used in this user guide were provided by NASA and the Japan Aerospace Exploration Agency (JAXA). The Orbit Viewer is written in the Interactive Data Language (IDL), which is manufactured by Harris Geospatial [https://www.harrisgeospatial.com/IDL]. If you have questions about the Orbit Viewer, please contact the Precipitation Processing System (PPS) Helpdesk at [helpdesk@mail.pps.eosdis.nasa.gov] or 301.614.5060. Alternatively, contact the Orbit Viewer developer at Owen.A.Kelley@nasa.gov, owen.kelley@pps.eosdis.nasa.gov, or 301.614.5245.

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1. INTRODUCTION

1.1 OVERVIEW

Orbit Viewer THOR is a tool for displaying the standard data products of NASA's GPM mission including the IMERG multi-satellite product and single-satellite products for the GPM core satellite, TRMM satellite, and an international constellation of satellites carrying passive microwave radiometers (imagers and sounders). IMERG stands for "Integrated Multi-satellitE Retrievals for GPM". GPM and TRMM stand for "Global Precipitation Measurement" and "Tropical Rainfall Measuring Mission," respectively, and the science team's website provides information about both satellites (https://gpm.nasa.gov). The THOR tool comes in the form of a desktop application that a researcher can install on his or her computer. THOR can also run as an online application, specifically an HTML/CSS/JavaScript program that is integrated into the STORM data ordering system (https://storm.pps.eosdis.nasa.gov/). Kelley [2013] describe the online version of THOR. The desktop version of THOR is the subject of the present document.

THOR enables a researcher to display any scientific data or metadata that is stored inside of a GPM or TRMM data file. For variables that can be displayed on a map, you can zoom until the map displays a single data point. For variables that cannot be displayed on a map, THOR provides a graphical or text-based display. THOR's dynamically created images are for on-screen display. This resolution may be sufficient for informal presentations (i.e., PowerPoint slides), but it is not intended to be publication quality.

Starting in March of 2014, the Global Precipitation Measurement (GPM) satellite has observed precipitation within approximately 65° of the Equator. From November of 1997 to 2015, the Tropical Rainfall Measuring Mission (TRMM) satellite observed precipitation within approximately 35° of the Equator. Both satellites are joint missions between the United States and Japan. The TRMM satellite carried the first satellite-borne radar capable of measuring the detailed three-dimensional structure of precipitation, while the GPM satellite carries the first dual-frequency precipitation radar in Earth orbit.

Since 1997, THOR has been developed by the Precipitation Processing System (PPS) at NASA's Goddard Space Flight Center. THOR stands for "Tool for High-Resolution Observation Review" [Kelley 2013], and the application runs under Linux, Microsoft Windows, and MacOS. THOR can be downloaded at no cost from the PPS Web site [https://pps.gsfc.nasa.gov].

In the fall of 1997, a few month prior to the launch of the TRMM satellite, PPS Project Manager Erich Stocker came up with the idea for a data viewer for PPS analysts and TRMM science-team members. Research Scientist Owen Kelley developed the prototype, which was rapidly put into service and was soon distributed on the PPS website for any researcher to download at no cost.

In 2009, Kelley completely rewrote the IDL code, preserving a core set of functionality and making it easier to add support for new data formats or functionality. The new release of THOR was designated THOR 2.0. In 2012, PPS began running an online version of THOR that was integrated into the STORM data ordering system. Kelley developed THORonline in HTML, JavaScript, CSS, and CGI [Kelley 2013]. In 2015, THOR 2.2 was released when the version of IDL underlying THOR was upgraded to IDL version 8.3.

Chapter 2 discusses installing THOR. Chapter 3 describes how to display data with THOR.

1.2 DATA

The GPM satellite carries two instruments for observing precipitation: the Dual-frequency Precipitation Radar (DPR) and the GPM Microwave Imager (GMI) [Hou et al. 2014]. The file format documentation and download instructions are available on the PPS website [https://pps.gsfc.nasa.gov]. The Japanese Aerospace Exploration Agency (JAXA) provides a more detailed file specification for the DPR data products [https://www.jaxa.jp].

GPM standard products are stored in the HDF5 format. THOR can read HDF5 files because it is written in the IDL language. IDL is manufactured by Harris Geospatial [https://www.harrisgeospatial.com/IDL]. You do not need to install the IDL language on your computer before running THOR because a stripped-down copy of IDL comes packaged within THOR.

The TRMM satellite carried five instruments including three precipitation-estimation instruments: the Precipitation Radar (PR), the TRMM Microwave Imager (TMI), and the Visible and Infrared Scanner (VIRS) [Kummerow et al. 1998]. For Lightning Imaging Sensor (LIS) data, contact Marshall Space Flight Center [https://lightning.nsstc.nasa.gov]. For Clouds and the Earth's Radiant Energy System (CERES) data, contact Langley Space Flight Center [https://ceres.larc.nasa.gov]. During 1998 to 2015, there were two periods during which TRMM data products may be affected by changes in the satellite's orbital altitude. In the first of these two periods (August 6 to 16, 2001), the TRMM satellite increased its orbiting altitude from 350 km to 402.5 km, an orbit change that conserved fuel and that thereby increased the duration of the TRMM mission. In the second of these two periods (July 1 to August 5, 2004), NASA forbade the TRMM satellite from maintaining its orbit, which caused the TRMM satellite to drop in altitude. The TRMM satellite's 402.5-km-altitude orbit was restored in early August 2004.

Starting in 2021, PPS provides access to GPM and TRMM datafiles using the HTTPS protocol, which is accessible with a web browser. The URLs for accessing the Production and Realtime data archives are as follow:

https://arthurhouhttps.pps.eosdis.nasa.gov/

https://jsimpsonhttps.pps.eosdis.nasa.gov/

To download files for free from the PPS archive, one must first register one's email address with PPS at this URL: https://registration.pps.eosdis.nasa.gov/. Once this email address is registered, it is used as both the username and password for logging into the arthurhouhttps and jsimpsonhttps archives. The FTP protocol was phased out by PPS for data access in 2021.

Users may also download TRMM and GPM standard products from the NASA Goddard Earth Sciences Data and Information Services Center (GES DISC) [https://disc.gsfc.nasa.gov/]. The organization was formerly known as the NASA Goddard DAAC (Distributed Active Archive Center).

Several terms are used in this user guide in very specific ways: algorithm, product, product, level, swath, and grid. An "algorithm" is a computer program that processes data. PPS obtains its algorithms from the US/Japan Joint Precipitation Science Team. A "product" is a kind of data file that is defined by a particular set of variables, by the algorithm that calculates these variables, and by a physical format (such as HDF5).

The "level" of a GPM or TRMM product indicates the degree to which the data have been processed. Some level 1 products contain instrument-independent physical variables such as radar reflectivity or brightness temperature in the original observation geometry of the instrument (i.e., the satellite's data swath). Other level 1 products contain engineering variables, such as returned power, that are instrument dependent. Level 2 products have been further processed so that they contain geophysical variables such as precipitation rate. Generally, level 2 products have the same "swath" observation geometry as the corresponding level 1 product. In contrast, Level 3 "gridded" products contain time-averaged and space-averaged data, such as monthly average precipitation rate in a rectangular latitude/longitude grid.

1.3 BUG REPORTS

If you find a bug in Orbit Viewer THOR, please contact the PPS Helpdesk at [helpdesk@mail.pps.eosdis.nasa.gov] or 301.614.5060. When asking the Helpdesk a question or reporting an error, please include the following information:

1. What operating system are you using? For example, is it Linux, Microsoft Windows, or MacOS? Please be as specific as possible. If you are running UNIX, please send the version of UNIX and the name of the UNIX shell that you are using. If you are running Mac, please send us the version you are running. You can determine the version by clicking on the Apple menu in the upper left of the screen and selecting "About this Mac."

2. What version THOR are you using? The version number is printed in zoom window when the THOR session begins.

3. Please mention any error messages that appeared on the screen. If you are running under UNIX, please start THOR with the "-e" option and try to recreate the error. Then, send us any error messages that were printed to the UNIX console.

4. What operation were you performing when the error occurred? For example, were you opening a file or creating a zoom image?

5. What is the name of the data file that you were displaying when the error occurred?

6. Have you purchased your own IDL license from Harris Geospatial, or are you using the embedded IDL license that comes with THOR?

2. INSTALLATION

The Orbit Viewer THOR can be installed on many computers that run Linux, MacOS, or Microsoft Windows. THOR is primarily designed to run under Linux. THOR normally runs in "freeware mode," which means its uses the IDL license within the THOR distribution. On Linux systems, THOR can be run alternatively in developer mode, which requires that you purchase an IDL license from Harris Geospatial. Experienced software developers may wish to run THOR in developer mode because developer mode allows modification of the THOR source code.

2.1 LINUX

Follow these steps to install the Orbit Viewer THOR on a Linux system.

Download THOR from [https://pps.gsfc.nasa.gov]. Download the zip file whose name contains the string "linux." This zip file contains 64-bit Linux software. Place the zip file in your "~" home directory. Never install THOR in a path where one of the directory names contains a space character.

Uncompress THOR. At the UNIX command prompt, type "unzip -qq *filename.zip*" to create the orbit directory.

Run the setup script. Go into the orbit directory ("cd orbit") and type "./setupUNIX.sh" to run the THOR setup shell script. The orbitUNIX.sh launch script should now exist in the orbit directory.

To enable you to easily launch THOR from any directory, create an alias. If your login shell is C or T shell, use "alias thor path/orbitUNIX.sh" where "path" is the absolute path to the orbitUNIX.sh launch script. Place this command in your .cshrc Linux startup file. Alternatively, if your login shell is bash or Bourne, use "alias thor=path/orbitUNIX.sh" to create the alias. Place this command in your .bash_profile Linux startup file. Thereafter, you should be able to launch THOR by typing "thor" on the Linux command line.

When launching THOR on a Linux system, the following command line arguments are available:

thor	Launch Orbit Viewer THOR without opening any file
thor [filename]	Open a file
thor -e [filename]	Open a file in error mode
thor -d [filename]	Open a file in developer mode
thor -i	Interactive mode
thor -h	Print usage instructions

By default, THOR is launched in "freeware" mode, i.e., you do not need to purchase any license before running it. Also by default, THOR launches in the background and operates silently. If an error occurs, restart THOR using the "-e" command line argument, which will cause THOR to print informational messages, warnings, and errors to the UNIX console. If you wish to modify THOR source code, then you will first need to purchase an interactive IDL license from Harris Geospatial, the manufacturer of IDL. Then, launch THOR in developer mode using the "-d" command line argument. If you launch THOR under Linux with the "-i" option, then an interactive IDL session is started with several useful procedures pre-compiled that you can use to read HDF4 and HDF5 variables into the IDL session.

The rest of this section provides tips on specific issues that may arise when you install THOR on a Linux system.

2.1.1 ELF file is ABI invalid

If THOR silently crashes when you type just "thor" on the linux command line, then try typing "thor -e" to print out error messages and warnings. When you type "thor -e" if you see an error message that your "ELF file" is "OS ABI invalid", then read on. The problem may be that you are running an out-of-date linux system that is too old to support the version of IDL that comes packaged within THOR. Starting with THOR version 2.2 (released in January of 2015), THOR is built with IDL 8.3, and IDL 8.3 only runs under linux version 2.6.32 or higher. Centos 5 linux is built with linux version 2.6.18, which is too old to run IDL 8.3, while Centos 6 is built with linux version 2.6.32, which is able to run IDL 8.3.

Here is the URL for the tech support article on this topic on the IDL website:
http://www.harrisgeospatial.com/Support/HelpArticles/TabId/185/ArtMID/800/ArticleID/13776/Error-ELF-file-OS-ABI-invalid-when-using-IDL-83-in-a-Linux-kernel-older-than-2632.aspx

One solution to this problem is available to anyone with a licensed copy of IDL already installed on their system. Such people can type "thor -d" to launch THOR using the copy of IDL already on their system, instead of the copy of IDL 8.3 that comes with THOR. If this solution is unavailable to you, then please contact the PPS Helpdesk [helpdesk@mail.pps.eosdis.nasa.gov], and we will attempt to assist you. [Release 2.2]

2.1.2 libXp.so.6 Under 64-bit Linux

When starting THOR on a 64-bit Linux system, IDL may crash and print the following error message to UNIX standard out:

```
error while loading shared libraries: libXp.so.6: cannot open
shared object file: No such file or directory
```

This error is known to occur on some Red Hat Linux and CentOS Linux systems. ExelisVISTech Tip #3923 discusses this error. The problem is due to IDL needing a different version of the X11 library than the version that is installed by default on some 64-bit Linux systems. The following commands, executed by the system's root user, may install the required version:

```
yum install libXp.x86_64
yum install libXp
```

[Release 1.3.6]

2.1.3 X Emulators and Dotted Lines

If THOR is running on a UNIX system, but you are displaying the results on the monitor of a Microsoft Windows system, you may experience difficulties with dotted lines. In some situations, all line styles other than solid will appear as dashed lines. This means that dotted lines and dash-dotted lines will be displayed incorrectly as dashed lines. The cause of the problem is your X windows emulator. The emulator is the software that allows your UNIX session to open a display on your Microsoft Windows monitor.

If you are using the MI/X X windows emulator, there is no known solution, but if you are using the Exceed X windows emulator, try the following steps: With the right mouse button, click on the Exceed bar at the bottom of the screen. In the menu that pops up, select Tools and then Configuration. In the exceed.cfg-Xconfig window that appears, double-click on Performance. In the Performance window, make sure that there is a checkmark in the box next to "Exact Zero-Width Lines." Click OK in the Performance window to dismiss it. [Release 1.3]

2.2 MAC

Follow these steps to install the Orbit Viewer THOR on a Mac desktop or laptop system.

Open a terminal window to your home directory. For decades, the user's home directory (the house icon) on the Mac's hard drive was the recommended location for personal files. Since THOR sits on top of the operating system and in no way modifies the operating system, the home directory remains the preferred location for installing THOR. Breaking with tradition, recent releases of the Mac operating system hide the user's home directory by default in the macOS Finder (the cubist blue/white face icon). To make your home directory visible in the Finder, start the finder. In the Finder menu in the upper left corner of the screen, select Preferences. In the Preferences pop-up window, select the Sidebar tab. In the Sidebar tab, check the checkbox next to the row that has the house icon followed by your username. Click the red button at the upper left of the Preference window to close the Preference window.

Because of THOR's heritage as a Linux application, the preferred method to install THOR under macOS is use the macOS Terminal utility. If you have not created a desktop icon for launching the Terminal utility, you can launch it by opening a Finder window and going to /Applications/Utilities/ and double clicking on Terminal.app. In 2019, the Terminal.app was briefly located in /System/Utilities/, but it is back to being located in /Applications/Utilities Once the Terminal utility opens, "cd" into ~[username], where [username] is the account you are logged into.

Download THOR from [https://pps.gsfc.nasa.gov]. Download the zip file that contains the string "mac." Place the zip file in your "~" home directory. Never install THOR in a path where one of the directory names contains a space character.

Uncompress THOR. To uncompress the file using software that comes with MacOS (i.e., Stuffit Expander), you can open a Finder window and double-click on the THOR zip file that you just downloaded. This operation should create an orbit directory in the same directory as the THOR zip file. You can also perform this task in the MacOS terminal utility by typing "unzip THOR*.zip".

Remove files from quarantine. As of 2019, MacOS places new program files in quarantine by default. Use the Terminal.app to remove the quarantine flag from the contents of the "orbit" directory immediately after creating it by uncompressing the THOR *.zip file. To do so, the following command in a terminal window in which you have "cd"ed to the directory that contains the "orbit" directory:

```
xattr -r -d com.apple.quarantine orbit
```

Run the setup script. Open the "orbit" directory in the Finder. One way to do so is using the terminal window in which you just typed the "xattr" command. Specifically, type "open orbit". In the Finder window, double-click on the setupMAC.command script. Verify that setupMAC.command created a Unix shell script called orbitUNIX.sh and a Mac application called orbitMAC.app. Alternatively, you could perform this task by typing "./setupMAC.command" in Terminal.app once it is in the orbit directory.

Test run the THOR launch script. In the same Finder window that you used to run the setupMAC.command setup script, verify that the THOR launch script works by double clicking on the orbitMAC.app application. In response, you system should launch the XQuartz X-windows emulator, and about 10 seconds later, open the THOR window.

Optionally, create a desktop shortcut. To create a shortcut, hold down the control key (ctrl) and click on the orbitMAC file. From the menu that pops up, select Make Alias. Drag the "orbitMAC alias" file that is created onto your desktop.

From now on, you should be able to launch THOR by double-clicking the orbitMAC file or any shortcut to that file. In addition, you can open a GPM HDF5 file by dragging and dropping that file onto the orbitMAC.app icon.

The rest of this section provides tips on specific issues that may come up when you install THOR on a Mac.

2.2.1 THOR quarantined under MacOS

In the fall of 2019, Apple released MacOS version 10.15 (codename: Catalina). This version of MacOS makes it difficult to run applications, like THOR, that are not signed with an Apple Developer ID. This tutorial recommends that you remove the "quarantine" flag from all of the files in the THOR distribution. Open the terminal application and change directories (cd) into the directory that contains THOR's "orbit" directory. Then, execute the following command:

```
xattr -r -d com.apple.quarantine orbit
```

This action removes the com.apple.quarantine flag from the resource file of each of the files in the orbit directory.

In releases of MacOS from 10.10 to 10.15, there was an alternate solution. In the upper left corner of your screen, click on the apple menu and select System Preferences from the pulldown menu. In System Preferences window, select Security&Privacy. In the General tab, you'll see the three possible settings for "Allow apps downloaded from." Just below those settings there may be a statement "setupMAC.command was blocked" with an "Open Anyway" button to the right of this statement. Click the Open Anyway button, which should unlock the THOR setup script. An equivalent operation is to control-click on the setupMAC.command on the Finder, then release the control key and hold down the option key. While holding down option key, click on the "Open" menu option in the pop-up menu. When prompted by the warning window, click the Open button.

While there are recommendations online that users disable the MacOS Gatekeeper ("sudo spctl --master-disable") to allow ordinary applications to run, but this tutorial does ***not*** recommend this action because it leaves your system in danger from any random application that you may download. [March 2021]

2.2.2. Z-shell

Starting in 2020, MacOS uses the z-shell by default for new accounts under MacOS instead of the BASH shell that /bin/sh has pointed to for years. The original setupUNIX.sh install script only works under BASH shell, not z-shell. For this reason, a separate setupZshell.script was created. To determine if you should use this alternate script, type "echo $0" on the Linux

command line. Do not use "echo $SHELL" because sometimes the $SHELL environment variable is misleading. If you determine that your account is using z-shell, then execute setupZshell.sh instead of setupUNIXsh and otherwise follow the same procedure for installing THOR. [April 2021]

2.2.3 MacOS XQuartz X-windows library refuses to launch THOR

In the fall of 2016, the XQuartz X-windows library (starting with XQuartz 2.7.10) is incompatible with the IDL startup script originally used by THOR. This issue can affect THOR only when it is run under MacOS. The THOR distribution has been updated to correct this issue. Anyone still running an older version of THOR that stops working following a MacOS system update may wish to consider downloaded an updated version of THOR from the PPS website. Alternatively, the user may edit the idl/bin/idl text script stored within THOR's "orbit" directory. Immediately below this line of code...

```
export DYLD_LIBRARY_PATH
```

...insert the following line of code:

```
export DYLD_LIBRARY_PATH=/opt/X11/lib/flat_namespace:$DYLD_LIBRARY_PATH
```

This solution is based on an IDL tech support article found on the Harris Geospatial website that was posted 24 October 2016 and titled: "XQuartz 2.7.10 is not compatible with ENVI 5.3.1 and IDL 8.5.1", available online at http://www.harrisgeospatial.com/Support/HelpArticlesDetail/TabId/219/ArtMID/900/ArticleID/14944/XQuartz-2710-is-Not-Compatible-with-ENVI-531-and-IDL-851.aspx .

2.2.4 X Windows

In late 2013, Apple released MacOS 10.9 "Mavericks", which removes the default version of X11 that was available on most MacOS systems prior to OX 10.9. Orbit Viewer THOR requires X11 to run. When you try running Orbit Viewer THOR on such a system, you may get the error "You need X11? Would you like to install it?" You can click "Yes" to install the XQuartz version of X11. [Release 2.1]

In 2014, Apple released MacOS 10.10 "Yosemite", in which you use a somewhat different mechanism to obtain X11. Under MacOS 10.10, open the Finder and go to Applications. Open Utilities. Double click on the X11 icon. A window will appear that asks if you want to install X11. Click "Yes" and follow the directions that appear on the screen. [Release 2.2]

2.2.5 The One-Button Mouse

If you are using a Mac one-button mouse and you want to do a right click, hold down the control (ctrl) key before clicking the mouse. [Release 1.3.5]

2.3 MICROSOFT WINDOWS

Follow these steps to install the Orbit Viewer THOR on a Microsoft Windows system.

Download THOR from [https://pps.gsfc.nasa.gov]. Place the THOR_*_win.zip zip file in the root directory of your hard drive, which is usually "C:\." Never install THOR in a path where one of the directory names contains a space character.

Uncompress THOR. Double-click on the My Computer icon on your desktop, and open the C:\ folder. To uncompress the file using software that comes with Windows, right-click on the zip file that you just downloaded and select Extract All from the menu that pops up. This operation should create a C:\orbit directory.

Run the setup script. Double-click to enter the orbit directory. Double-click on the setupWIN.bat setup script. Verify that the setup script created a batch script called orbitWIN.bat. To create a desktop shortcut, right-click on the orbitWIN.bat file, select Create Shortcut from the menu that pops up, and drag the shortcut file onto your desktop. Be sure that your desktop directory path does not contain any space characters, or THOR will not launch from that shortcut.

From now on, you should be able to launch THOR by double-clicking the orbitWIN.bat file or any shortcut to that file (pending the caveat above). In addition, you can open a PPS data file by dragging and dropping the file onto the orbitWIN.bat file.

3. DATA DISPLAY

3.1 STARTING THE SOFTWARE

Before examining data, you must launch Orbit Viewer THOR. To launch THOR on a Linux system, run the orbitUNIX.sh shell script in the orbit directory or type "thor" at the Linux command line if you have setup an alias to orbitUNIX.sh. To launch THOR on a Microsoft Windows or Mac system, double-click on the "C:\orbit\orbitWin.bat" file or "orbitMAC", respectively. If you have not yet installed THOR, see the installation instructions in Chapter 2.

A sample HDF file (a TRMM TMI 2A12.*.HDF subset file) is provided with THOR as the first item in the Data folder under the main Orbit folder. To download other PPS data files, go to the following URL with your web browser: https://pps.gsfc.nasa.gov. On that page, select Data from the left menu and choose TRMM Public Data Archive. Select By Date, then V07, and last select data that is ordered by algorithm name. On a Microsoft Windows system, be sure that you have installed Winzip or a similar program on your computer so that you can you can uncompress the *.gz files from the PPS archive before opening the files in THOR.

To open a file, select the File→Open menu item in the upper left of THOR's main window. Alternatively on a Linux system, you can include the filename on the command line when you launch THOR. On a Windows or Mac system, you can open an HDF file by dragging and dropping the file onto the Orbit icon (C:\orbit\orbitWIN.bat or orbit/orbitMAC).

Once a file is open, the left side of THOR's main window will show the list of the objects that the file contains. To display an object, click on its name in the list. To open a folder, click on the plus sign to the left of the folder's name or double-click on the folder's name.

If the object that you selected can be displayed on a map of the Earth, then it will be displayed in the Map tab on the right side of THOR's main window (Figure 3.1). If this array contains more than two dimensions, then click on the Array tab on the left side of THOR's main window to select which element of the additional dimension or dimensions to display. You select an element by moving the appropriate slider widget with your mouse (the slider is visible with a variable with three or more dimensions). Alternatively, to nudge the slider over in increments of 1 you can use the arrow keys. By default, THOR displays the "zeroth" element of each additional dimension of an array.

When examining numeric data, it is important to remember that THOR is a zero-based application. For example, sliders go from zero up to one less than the number of elements in a dimension. In addition, the axes of plots also go from zero to one less than the number of elements in a dimension.

3.2 THE MAIN WINDOW

When learning to use THOR, it can be helpful to keep in mind the general layout of THOR's main window (Figure 3.1). The left half of the window contains tabs for selecting data. The right half of the window contains tabs for displaying data that you have selected, whether on a map of the Earth, as an image, or as text. The following paragraphs describe these tabs and other parts of the THOR main window.

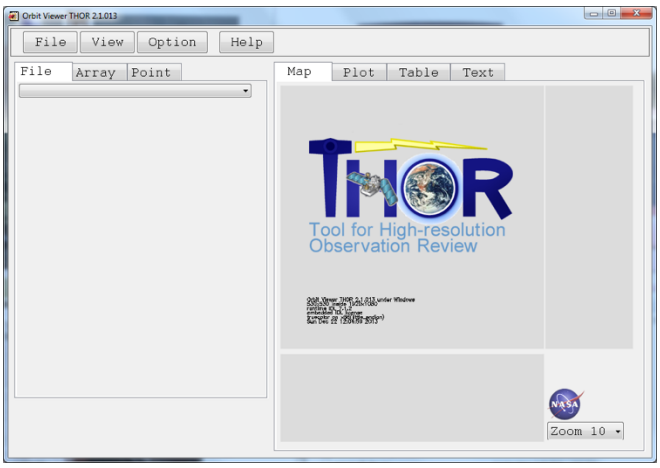

Figure 3.1. THOR's main window.

Along the top of THOR's main window is a Menu bar (File, View, Option, and Help menus) that enables you to perform various functions or change display settings from their default value.

The File menu permits you to do the following:

- Open File: Open a data file for viewing.
- Close File: Close the data file you are viewing.
- New Window: Open a new THOR Orbit Viewer graphical user interface (GUI).
- Save Image: Save to disk an image currently displayed in one of THOR's tabs.
- Save Data: Save one or more variables from the presently open file into a new data file.
- Quit: End the session and close the GUI.

The View menu permits you to do the following:

- Refresh: Regenerates the image.
- Goto: Open a window that lets you center the zoom window on a user-specified lat/lon location.
- Object: 1) View Attributes: Display any attributes that may be attached to the currently selected data object. 2) View Properties: A separate window pops up to display the file's properties. 3) Assign Lat/Lon: A separate window pops up and allows you to associate

latitude and longitude arrays with a variable. 4) CDF in File: View the cumulative distribution function of the actual values in the file. 5) CDF Unscaled: View the cumulative distribution function of an object's values after any available scaling factor is applied to the object. 6) View as Text: View the entire data array in a list format.
- Swath: 1) 3D View: Display 3D radar reflectivity or precipitation rate with an isosurface. 2) Global Find: Locate specific values in a swath. 3) Plot with Circles: When zoomed in on the map, view each field of view as a circle.

The Option menu permits you to do the following:

- Color Table: Change the colors in the color table and the mapping of data to the color table (see Section 3.10).
- Map Projection: Change the map projection used to display data on a map of the Earth.
- Shrink/Expand Window: Hide or show the left side of the Main Window.

The Help menu permits you to do the following:

- Debug: 1) Profiler: Diagnose slow performance in the Orbit Viewer software. Click once to activate, and a second time to view the report. 2) Console: Open a limited command line to diagnose IDL settings and compiled procedures. 3) Color Test: View all colors used by the Orbit Viewer to verify monitor settings. 4) Reload Static Colors: Reload the color table configuration file that you have edited (data/static_color.txt file).
- About Viewer: Display information about the Orbit Viewer THOR.
- Note: Next to the Help button along the menu bar is a set of numbers, i.e., 16M/19M. These numbers represent the current memory usage and the session's maximum memory usage, respectively.

3.3 FILE TAB

The File tab is located on the left side of the THOR main window, and is shown in Figure 3.2. If multiple files are currently open, the drop-down menu at the top of the File tab permits you to select among the open files. Below the drop-down menu is a list of objects contained in the currently selected file. Text objects, such as metadata fields, are preceded by a text icon. When you click on a text object, it is displayed in the Text tab on the right side of the main window. Folders are preceded by an open or closed folder icon. Data objects are preceded by a square icon. When you click on a data object, it will be displayed, by default, in the Map or Plot tab depending on whether the data object can be geolocated on a map of the Earth.

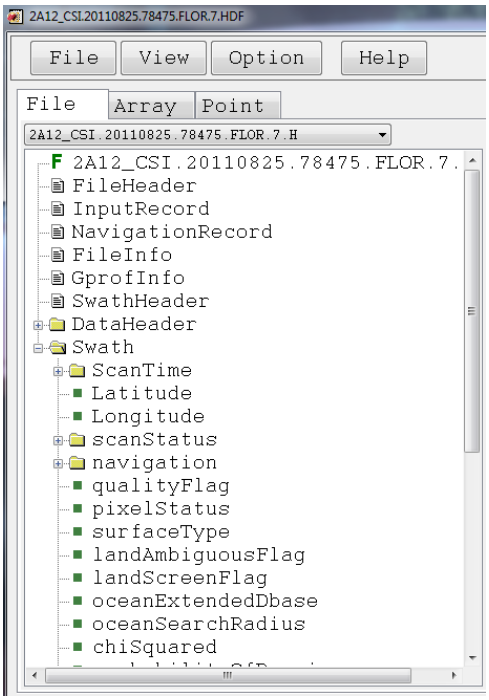

Figure 3.2. The File tab.

3.4 ARRAY TAB

The Array tab is located on the left side of the THOR main window. The Array tab enables you to select a one-dimensional or two-dimensional subset of the variable that you have previously chosen in the File tab.

If the selected variable contains three or more dimensions, one can change which two-dimensional slice is displayed by moving the sliders in the Array tab. For the 3D precipitation rate variable shown in the figure, the Array tab is set to show a horizontal cross-section on a map of the Earth because all fields-of-view (fov) and all scans are currently displayed. If you wish to display a vertical cross-section of the array, use the pull-down menu at the bottom of the Array tab to select one or two other variables to display. For example, to display a cross-track vertical cross-section, select the "layer+fov" item from the pull-down menu.

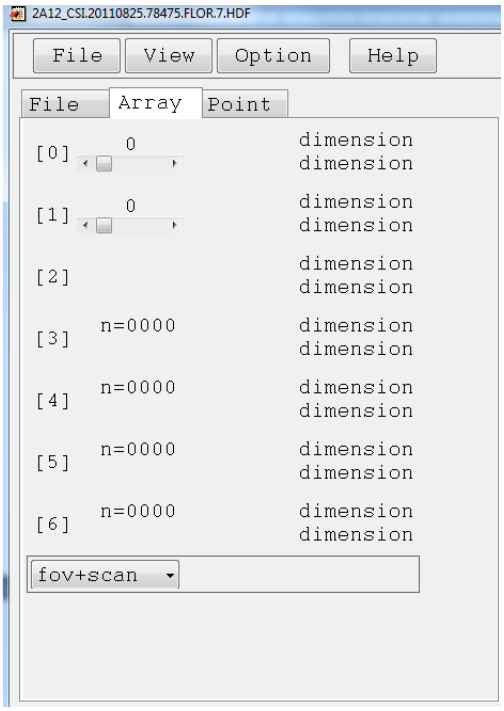

Figure 3.3. The Array tab.

3.5 POINT TAB

The Point tab is located on the left side of the THOR main window. The Point tab displays information about a single point of a data array that is displayed on a map of the Earth. The information printed in the Point tab varies depending on the array being displayed, but generally the information includes the location of the point, its data value, and the time that the observation was made. A point is selected by clicking on the Map tab on the right side of the main window, as described in Section 3.6. The colored box at the bottom of the Point tab identifies the color with which the data point is displayed in the Map tab.

The Option menu at the bottom of the Point tab enables you to do the following:

- Select Extra Variables: By default, the Point tab prints out the value of only the currently displayed variable and at the array index selected when the user clicked on the Zoom image. Use the Select Extra Variable menu item and pick additional variables if you want their values also printed at the selected array index.
- Disable Selected Point: By default, THOR will continue to display with a plus sign the location of the selected point even when you adjust the location of the Zoom image. If you no longer want the selected point highlighted, select the Disable Selected Point menu option.

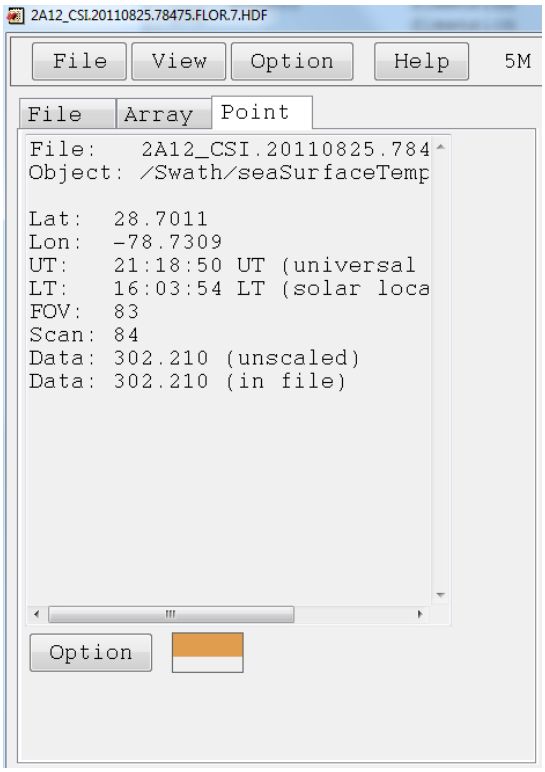

Figure 3.4. The Point tab.

3.6 MAP TAB

Initially, the lower portion of the Map tab shows the entire spatial extent of the data (Figure 3.5). To zoom in, click on the lower portion of the Map tab. In response, THOR will display a zoom image in the upper portion of the Map tab. A companion Color bar will be displayed to the right of the zoom image. Along the left side of the Color bar is a vertical line; this line indicates the range of data being displayed on the map or plot. The small horizontal cross bar indicates the median data value being displayed. To zoom in closer on the map, use the pull-down menu on the lower right corner of THOR's main window. You can re-center the zoom window by dragging the cursor across the zoom window. Obtain information about a single data point in the zoom window by clicking on the zoom window. The information about that data point will appear in the Point tab on the left side of THOR's main window.

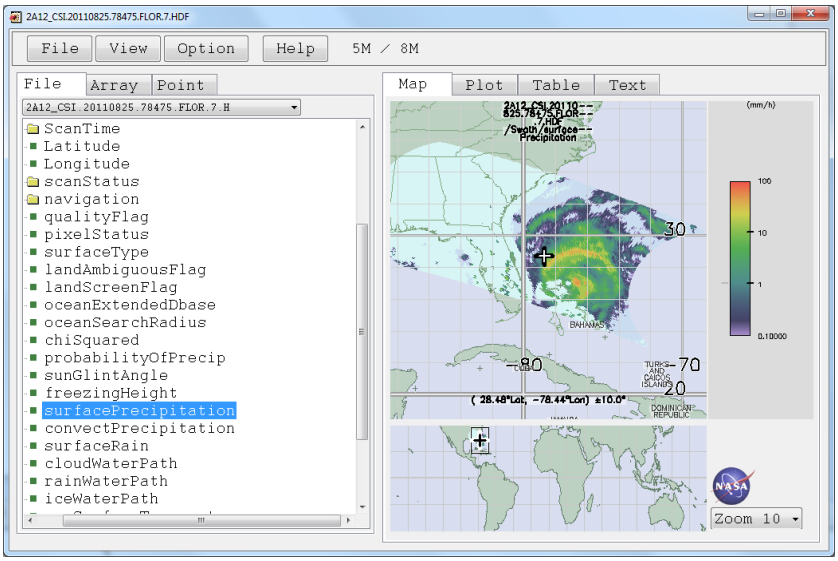

Figure 3.5. A swath array displayed on a map of the Earth.

3.7 PLOT TAB

There are situations in which it is helpful to display an array that cannot be shown on a map of the Earth. In these situations, click on the Plot tab of THOR's main window.

Figure 3.6 shows an image in the Plot tab on the right of the THOR main window and the Array tab displayed on the left side of the THOR main window. By default, the entire two-dimensional array is shown in the image.

To zoom in on an image displayed in the Plot tab, use the expansion buttons (↔and ↕) along the bottom of the Plot tab. At the bottom of the Plot tab, there are also shift buttons (↑, ↓, ←, and →) that you can use to shift the plot up, down, left, and right, respectively. In the lower left corner of the Plot window is a small gray box that indicates which area of the plot is being viewed. To return the plot to the original full-extent view, click on the blue Box button next to the Zoom buttons at the bottom of the Plot tab.

The Option menu at the bottom of the Plot tab permits you to do the following:

- Transpose X, Y: Transpose or swap the X and Y axes.
- Reverse X and Reverse Y: Reverse values on the X axis and the Y axis, respectively.

For arrays with more than two dimensions, use the sliders in the Array tab on the left side of the THOR window to select which element is to be displayed from the additional dimensions.

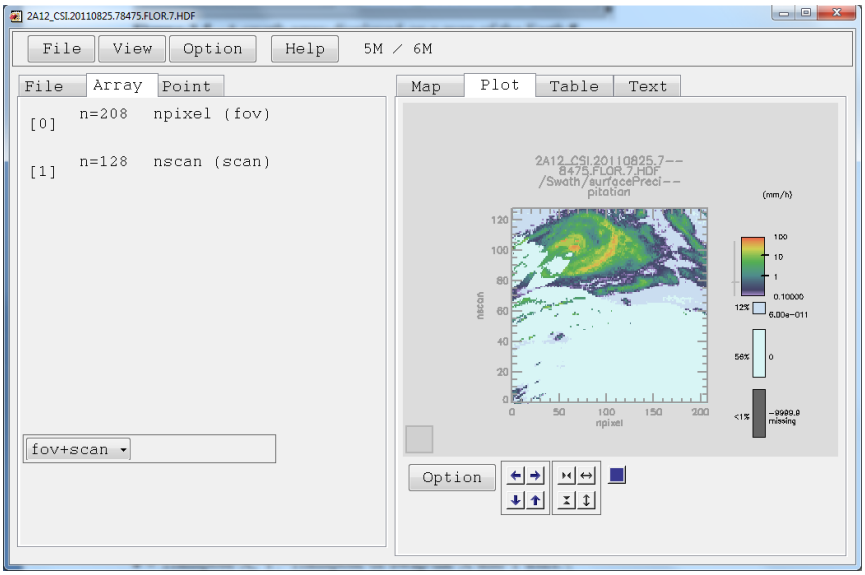

Figure 3.6. An image in the Plot tab.

If you wish to switch to a one-dimensional line plot of the variable, select the dimension of interest from the pull-down menu near the bottom of the Array tab on the left side of the THOR main window (Figure 3.7).

Figure 3.7. A line plot in the Plot tab.

3.8 TABLE TAB

The Table tab is located on the right side of the THOR main window, as shown in Figure 3.8. An object displayed graphically in the Map or Plot tab can have its numerical values examined in the Table tab.

Click on the Table tab when you want to see a text print-out of a portion of a data array. Use the horizontal and vertical sliders to change which portion of the object is displayed in the table. If you want to change which dimensions are displayed, use the pull-down menu at the bottom of the Array tab on the left side of the main window. The Option menu at the bottom of the Table tab allows you to do the following:

- Change Cell Format: Change the format of the numbers displayed in the table to floating point or integer.
- Save Table: Save a table to a directory on your computer.

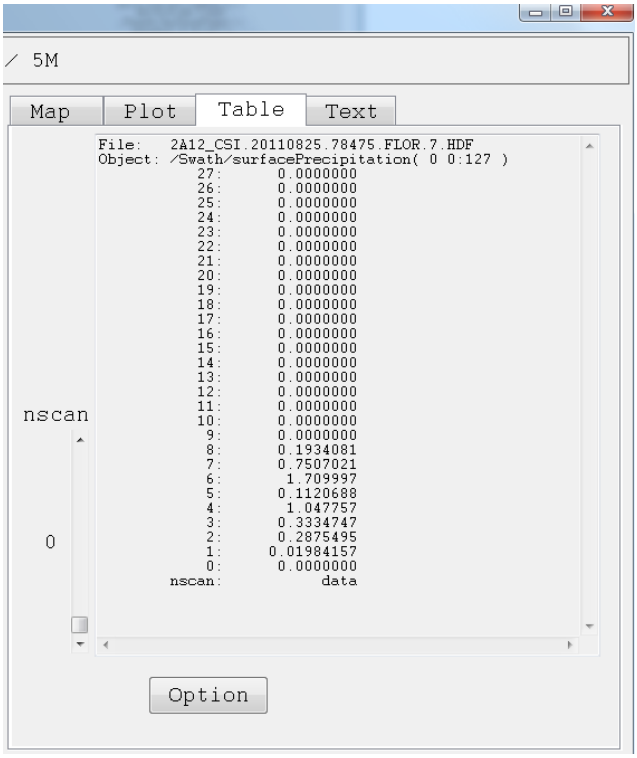

Figure 3.8. The Table tab.

3.9 TEXT TAB

The Text tab is located on the right side of the THOR main window, and is shown in Figure 3.9.

File metadata and other text objects in a data file are displayed in the Text tab. If THOR displays a text object incorrectly as if it were numeric data, select the View→Object→ViewAsText menu item to display the object as text in the Text tab. If you wish to see the metadata attributes of an individual object, select the View→Object→ViewAttributes menu item.

The example in Figure 3.9 shows the Core Metadata object of a TRMM version 6 HDF file. If you wish to search for a word within the text displayed in the Text tab, type the word in the text field at the bottom of the Text tab and click the Find button. The Option button allows you to split a single long line of text into shorter earlier-to-read lines and allows you to save the text to a file.

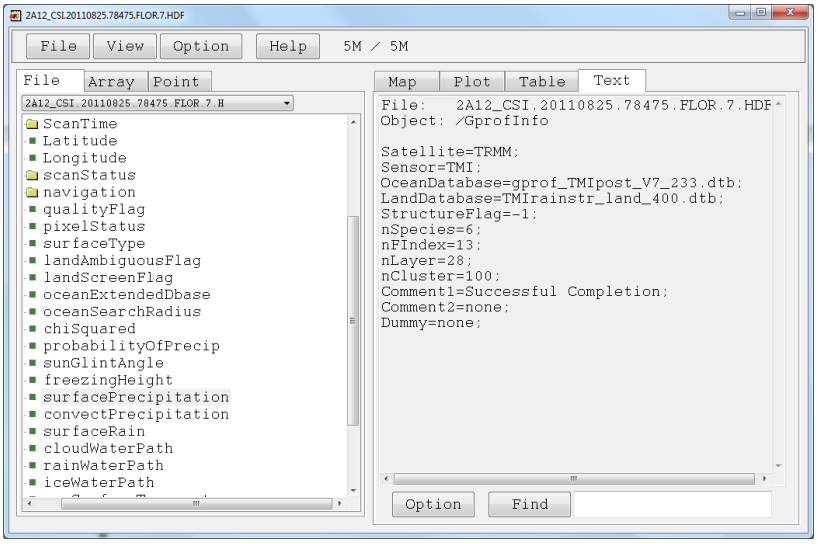

Figure 3.9. The Text tab.

3.10 COLORS

When possible, THOR uses a static color table for displaying an array, regardless of the range of values that the array may take in an individual file. A static color table makes it possible to easily compare the same array from two different time periods, such as precipitation rate estimated from two different orbits of the GPM satellite. The static color tables are stored in the orbit/data/static_color.txt text file. You can edit this text file to suit your preferences.

When a static color table is available for a variable, then the variable is plotted using rainbow colors with the specified data values mapped to the bottom color and top color. The static color table also specifies whether the data is mapped to the color table either linearly or logarithmically. Logarithmic mapping is appropriate for variables such as precipitation rate that

can take on a large range of values, but for which most observations are near the bottom of that range.

When a static color table is unavailable, THOR plots the variable in muted colors. The data value mapped to the top and bottom of the color table are chosen based on the values in the particular file that is currently open.

You can alter the color table using the Option→Color Table menu item. When this menu item is selected, an Color Table window appears. The Color Table window has three tabs, a Data tab, a Color tab, and a Size tab. Figure 3.10 shows the Data tab of the Color Table window.

At the top of the Data tab, you can change the data values that are mapped to the top and bottom of the Color bar. To the right of these fields, a pull-down menu permits you to change whether the data values are mapped logarithmically or linearly between the specified upper and lower bounds. At the bottom of the Data tab is a list of the known "special values." In many arrays, a value of -9999 indicates missing observations, for example. At the left edge of each row, a box indicates if the special value is currently active. By default, THOR looks for all currently active special values when displaying an array. If any data points have one of these special values, then the color table on the right of the Map and Plot tabs will indicate the existence of that special value. You can "turn off" any special value by unchecking the box on the left edge of that special value's row in the Data tab of the Color Table window. Click the Apply button to apply any changes made to the color table. The Dynamic button will apply the grayscale and dynamically adjust the min/max to maximize contrast. The Reset button will reset all of the default values and the color scale.

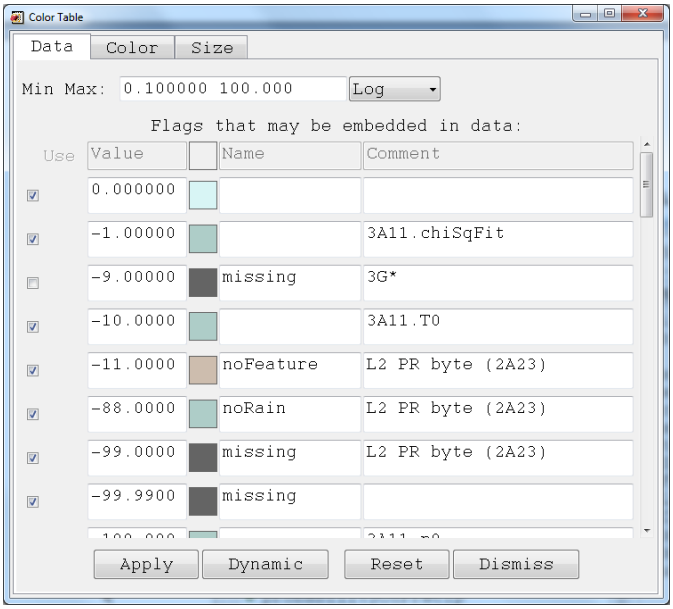

Figure 3.10. Altering the data limits of the color table.

The Color tab of the Color Table window allows you to stretch the color table using sliders and to switch to an entirely different set of colors for displaying continuous data. The Reset and Reverse buttons on the Color tab allow you to change your color set or return it to the default color set. Figure 3.11 shows the Color tab.

The Size tab in the Color Table window allows you to change the size of point symbols used to plot some arrays.

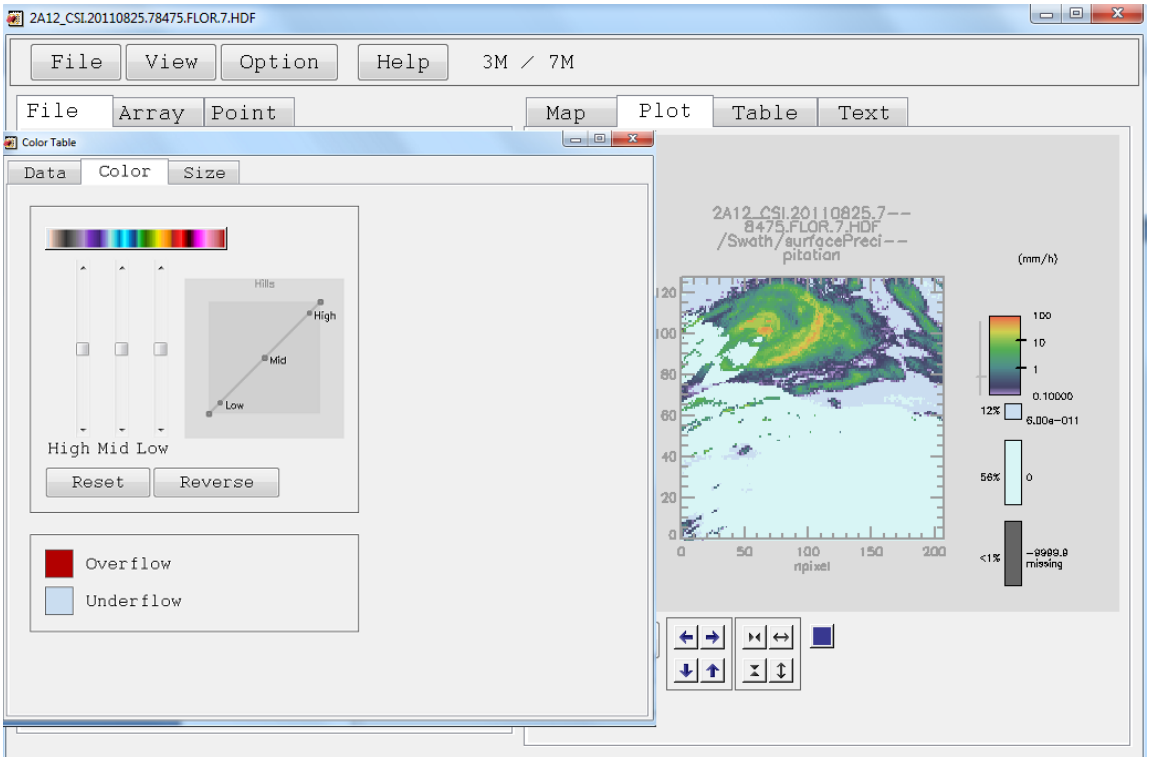

Figure 3.11. Altering the colors in the color table.

3.11 3D VIEW

A variables in GPM and TRMM data products provide 3D representations of precipitation. THOR can display several of them as 3D isosurfaces, i.e. a volume that contains all points that exceed a specific data value. The variables that THOR can display in 3D are attenuation-corrected radar reflectivity and radar-estimated precipitation rate. These quantities are contained in the GPM 2AKu, 2AKa, and 2ADRP data products and TRMM 2AKu data product.

The following example uses the GPM Ku zFactorCorrected variable which contains 3D radar reflectivity in units dBZ. First, open a GPM 2AKu HDF5 file and select in the left-hand column the zFactorCorrected variable. Click on the global region to select a zoom region. Select the

View→Swath→3D View menu option. After a short delay to format the data, a window such as the following one will open to display the data.

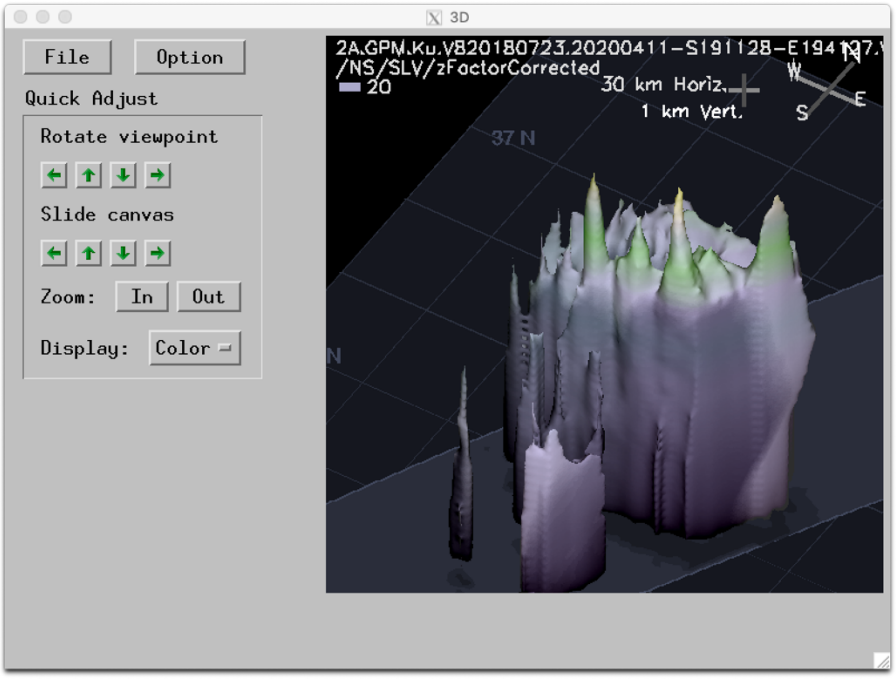

Figure 3.12. 3D Window

To change the angle and position of the view-point, you use the arrow buttons in the Quick Adjust box of the 3D window. The buttons labeled "Rotate viewpoint" allow you to increase or decrease the azimuth angle and elevation angle of the viewpoint. The buttons labeled "Slide canvas" moves the position of the canvas to the left, up, down, or right. As one would expect, the Zoom In and Out buttons increase or decrease the zoom factor of the image. By default, the 3D image is in color, but a grayscale image can be generated if one changes the Display pulldown from Color To Gray. Grayscale images can be generated much faster than color images, so the grayscale is useful when doing many adjustments to the view-point. The File menu of the 3D window allows you to save the 3D image in a PNG file.

The Option menu allows you to change the types of image controls displayed. Most users will only use the following two options in the Option menu: Quick adjust and Threshold. The Quick adjust box was described above. The Threshold box allows you to change the data value of the threshold that defines the outer isosurface displayed in the image. By default, only the outer isosurface is displayed in the image. If you wish to see the inner isosurface nested within the outer isosurface, then increase the Inner Fraction text field from 0.0 to some value less than 1.0, such as to 0.5. After typing a new value in the Inner Fraction text field, type the enter key. The 3D image-generation routines were written in IDL as described by Kelley [2013, *Computers & Geosciences,* pp. 228-237].

4. REFERENCES

Hou, A. Y., R. K. Kakar, S. Neeck, A. Azarbarzin, C. D. Kummerow, M. Kojima, R. Oki, K. Nakamura, and T. Iguchi, 2014: The Global Precipitation Measurement (GPM) mission, *Bulletin of the American Meteorological Society*, in press.

Kelley, O. A., 2013: Adapting an existing visualization application for browser-based deployment: A case study from the Tropical Rainfall Measuring Mission, *Computers and Geosciences*, **51**, 228–237.

Kummerow, C., W. Barnes, T. Kozu, J. Shue, and J. Simpson, 1998: The Tropical Rainfall Measuring Mission, *J. Atmospheric and Oceanic Technology*, **15**, 809–817.

5. GLOSSARY

CERES – Clouds and Earth's Radiant Energy System. One of the TRMM instruments.

color table – The ordered set of colors used in an image with pixels generally no larger than eight bits. Eight-bit devices generally have a maximum of 256 colors in their color tables. Each color in a color table is usually defined by a red-green-blue (RGB) triplet.

DAAC – Distributed Active Archive Center. The Goddard Earth Sciences DAAC archives and distributes GPM and TRMM data to the public. In recent years, the Goddard DAAC has been called the Data and Information Services Center (DISC). [https://disc.sci.gsfc.nasa.gov/]

dpi – Dots per inch.

DPR – Dual-frequency Precipitation Radar. The radar on the GPM satellite.

EORC – Earth Observation Research Center. An organization within JAXA. [https://www.eorc.jaxa.jp/en/index.html]

ESRI – Environmental Systems Research Institute. The company that makes the Arc line of Geographic Information System (GIS) software. [https://www.esri.com]

fov – Field of view. A data point within a satellite data swath.

FTP – File Transfer Protocol. A popular way to transfer files between computers. Anonymous FTP sites allow you to download files using "anonymous" as the username and your e-mail address as the password. In 2021, PPS replaced FTP access to the GPM archive in favor of FTPS and HTTPS.

GIF – Graphic Interchange Format. The GIF image format uses loss-less compression and can be displayed by Web browsers.

GIS – Geographical Information System. A kind of application for generating and analyzing maps.

GMI – GPM Microwave Imager. The passive microwave instrument on the GPM satellite.

GPM – Global Precipitation Measurement. A precipitation-measurement satellite built by NASA and JAXA and launched in 2014.

GSFC – Goddard Space Flight Center. GSFC is NASA's research center in Greenbelt, Maryland. PPS and the Goddard DAAC are located at GSFC. [https://www.gsfc.nasa.gov]

GUI – Graphical user interface.

HDF – Hierarchical Data Format. A binary data format first developed by NCSA in the late 1980s and adopted by NASA for its Earth-observing data in the early 1990s. [https://www.hdfgroup.org/]

ICS – Interface Control Specification.

IDL – Interactive Data Language. This high-level programming language is developed by Harris Geospatial, and it is the language in which the Orbit Viewer THOR is written. IDL combines the ease a high-level language with some of the computation speed of low-level languages. It also has built-in features useful to scientists such data-format access, graphical user interfaces, and computation procedures.

JAXA – Japan Aerospace Exploration Agency. JAXA is the Japanese Government's counterpart to NASA. Prior to October 2003, this organization was called the National Space Development Agency (NASDA). [https://www.jaxa.jp]

JPEG – Joint Photographic Expert Group. The JPEG image format uses lossy compression and so is not well-suited for images that contain text or lines.

LIS – Lightning Imaging Sensor. One of the TRMM instruments. Pronounced "liz."

MacOS – The UNIX-based operating system of Macintosh computers.

mm/h – Millimeters per hour. The unit of precipitation rate. One inch per hour is 25.4 mm/h.

NASA – National Aeronautics and Space Administration. A Government agency in the United States of America. [https://www.nasa.gov]

NICT – The National Institute of Information and Communications Technology. Prior to April 2004, this organization was called the Communications Research Laboratory (CRL). CRL built the TRMM Precipitation Radar. [https://www.nict.go.jp]

PMM – Precipitation Measurement Missions. The NASA science team for both the TRMM and GPM satellites.

PNG – Portable Network Graphic. The PNG image format was developed in the 1990s, and most web browsers can now display it. PNG uses loss-less compression. [https://www.libpng.org]

PPS – The Precipitation Processing System at NASA GSFC. The organization that processes GPM and TRMM data to create the TRMM standard products. Prior to June 2008, this organization was called TSDIS. [https://pps.gsfc.nasa.gov]

PR – Precipitation Radar. An instrument on the TRMM satellite.

THOR – Tool for High-Resolution Observation Review. The current version of the Orbit Viewer, which is a tool for displaying GPM and TRMM standard products produced at NASA's Precipitation Processing System at the Goddard Space Flight Center.

TIFF – Tagged Image File Format. An image format with loss-less compression.

TMI – TRMM Microwave Imager. An instrument on the TRMM satellite.

TRMM – Tropical Rainfall Measuring Mission. Pronounced "trim." A precipitation-measurement satellite built by NASA and JAXA and launched in 1997.

TSDIS – TRMM Science Data and Information System. Prior to 2008, the former name of the NASA Goddard Precipitation Processing System (PPS).

VIRS – Visible and Infrared Scanner. An instrument on the TRMM satellite.